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WEATHER AS A BUSINESS RISK IN FARMING[1]

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No type of agriculture can be successfully established in a region where the risk of loss by drought, frost, or other unfavorable conditions is not more than balanced by the profits at other times. If the farmer is to succeed as a business man, he should know the degree of risk involved in raising a given crop at a given time. Among the business risks of farming those that grow out of unfavorable weather conditions are of chief importance. The result is that there are a growing number of maps which show in detail distributions of meteorological phenomena of all sorts. This investigation and the maps accompanying it attempt to combine the facts hitherto known in a manner that shows the risk of loss from unfavorable weather.

Climatic data expressed in averages afford a basis for determining the general character of a region but give no indication of the frequency or magnitude of departures from the average. Averages are a convenient method of stating the points about which the actual conditions fluctuate, but otherwise they are of minor importance to the farmer.[2] For example, the average date of last killing frost in spring at La Crosse, Wisconsin, is April 26. An examination of the frost record for La Crosse, Table I, shows that the last frost occurred before the average date in twenty-two of the forty-two years of record, and after the average date in twenty years. In other words a crop in a condition to be damaged on April 26 would be destroyed about half the time, that is, the risk of damage by frost on that date is approximately fifty per cent,[3] or more than most crops can bear.

One method of meeting this difficulty has been the statement of the latest recorded date of spring frost at each station; but such data are of doubtful value in the determination of the risk from frost damage, as they rest upon single occurrences and, moreover, represent different things in different places on account of the varying length of the records. On the assumption that the period covered by the record represents conditions

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[1] Substance of a paper presented at the Washington meeting of the Association of American Geographers, December 30-31, 1915, and January 1, 1916.

The writers wish to record their obligation to Prof. W. J. Spillman, Chief of the Office of Farm Management, U. S. Department of Agriculture, for the original suggestion of this method for determining risk and for advice and assistance at all stages of the study.

[2] For a discussion of the meaning of average values in meteorology see H. Meyer: Anleitung zur Bearbeitung meteorologischer Beobachtungen für die Klimatologie, Berlin, 1891, pp. 19-27.

[3] This percentage of risk is true only in the case of phenomena for which the mean and the median have essentially the same value. Such is the case with the dates of last spring and first autumn frost and probably with some temperature phenomena. It is not the case with rainfall amounts, although it may be with the occurrence of rainfalls of certain fractions of the average amount.

Table I—Frost Data

LaCrosse, LaCrosse County, Wisconsin

Latitude 43°49′ N.; Longitude 91°15′ W.; Altitude 681 feet

Last killing frost in spring				First killing frost in autumn			
Year	Date	Departure from average date		Year	Date	Departure from average date	
		Days	Square			Days	Square
1906	April 2	— 24	576	1889	Sept. 21	— 21	441
1901	April 3	— 23	529	1893	Sept. 24	— 18	324
1903	April 4	— 22	484	1888	Sept. 29	— 13	169
1886	April 7	— 19	361	1908	Sept. 29	— 13	169
1898	April 7	— 19	361	1873	Sept. 30	— 12	144
1902	April 7	— 19	361	1883	Oct. 1	— 11	121
1900	April 9	— 17	289	1886	Oct. 1	— 11	121
1896	April 10	— 16	256	1899	Oct. 3	— 9	81
1899	April 10	— 16	256	1901	Oct. 4	— 8	64
1894	April 11	— 15	225	1876	Oct. 5	— 7	49
1882	April 16	— 10	100	1881	Oct. 5	— 7	49
1877	April 18	— 8	64	1885	Oct. 5	— 7	49
1905	April 18	— 8	64	1887	Oct. 5	— 7	49
1912	April 19	— 7	49	1877	Oct. 6	— 6	36
1914	April 20	— 6	36	1904	Oct. 6	— 6	36
1884	April 21	— 5	25	1896	Oct. 7	— 5	25
1897	April 21	— 5	25	1895	Oct, 8	— 4	16
1904	April 21	— 5	25	1907	Oct. 8	— 4	16
1893	April 23	— 3	9	1891	Oct. 9	— 3	9
1875	April 24	— 2	4	1894	Oct. 9	— 3	9
1887	April 24	— 2	4	1897	Oct. 9	— 3	9
1874	April 25	— 1	1	1906	Oct. 10	— 2	4
1913	April 27	+ 1	1	1880	Oct. 12	0	0
1892	April 29	+ 3	9	1874	Oct. 13	+ 1	1
1873	April 30	+ 4	16	1902	Oct. 14	+ 2	4
1878	May 1	+ 5	25	1909	Oct. 14	+ 2	4
1876	May 2	+ 6	36	1898	Oct. 15	+ 3	9
1908	May 3	+ 7	49	1875	Oct. 16	+ 4	16
1907	May 4	+ 8	64	1913	Oct. 18	+ 6	36
1911	May 4	+ 8	64	1878	Oct. 19	+ 7	49
1891	May 5	+ 9	81	1882	Oct. 19	+ 7	49
1880	May 6	+ 10	100	1892	Oct. 19	+ 7	49
1890	May 7	+ 11	121	1890	Oct. 21	+ 9	81
1909	May 10	+ 14	196	1905	Oct. 21	+ 9	81
1885	May 11	+ 15	225	1884	Oct. 22	+ 10	100
1879	May 13	+ 17	289	1910	Oct. 22	+ 10	100
1888	May 13	+ 17	289	1912	Oct. 23	+ 11	121
1895	May 14	+ 18	324	1879	Oct. 24	+ 12	144
1881	May 21	+ 25	625	1903	Oct. 24	+ 12	144
1883	May 21	+ 25	625	1911	Oct. 24	+ 12	144
1889	May 22	+ 26	676	1914	Oct. 27	+ 15	225
1910	May 24	+ 28	784	1900	Nov. 7	+ 26	676

Average date April 26

Standard deviation $= \sqrt{\frac{8703}{42}} = 14.4$

Risk of frost falls to 25% May 6

Frosts occurred after May 6 in 10 years of the 42

Risk falls to 10% May 15

Frosts occurred after May 15 in 4 years of the 42

Average date Oct. 12

Standard deviation $= \sqrt{\frac{4023}{42}} = 9.8$

Risk rises to 10% Sept. 29

Frosts occurred on or before Sept. 29 in 4 years of the 42

Risk rises to 25% Oct. 5

Frosts occurred before Oct. 5 in 9 years of the 42

exactly average in all respects, it is possible to get a very good idea of the percentage of risk after any given date by counting the years in which a killing frost has occurred after this date.[4] It is not likely, however, that the data for extreme cases for any available period will represent exact average conditions. The actual character of the distribution of all occurrences should furnish a much better guide to the risk with reference to a given number of days after the average date.

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[4] See Cleveland Abbe: Frequency of Injurious Phenomena, *Monthly Weather Rev.*, Vol. 27, 1899, pp. 59-60.

There is no record of climatic data for any place in the United States which is of sufficient length to result in a smooth distribution of actual occurrences around the average. The longest available records are those of rainfall, and they are not much over one hundred years in length, while over five hundred observations are generally required to obtain smooth distribution. Frost records are much shorter still, the longest one available covering a period of fifty-nine years. This gives a number of observations much too small to permit the construction of a usable frequency polygon.[5]

The characteristic dispersions of the dates of last killing frost in spring are shown by Figure 1, which was compiled from the records of five stations with different types of dispersion. The figure shows the way in which these dates are actually distributed. The lack of a sufficient number of data to give a smooth polygon may be overcome for phenomena in which the distribution for all stations follows the same type of frequency curve by adding together the records for several stations. If the addition of data from other stations does not change the shape of the frequency polygon but merely tends to smooth the irregularities, it is clear that the distribution for all the stations is similar; or they may be complementary in some cases—a "skew" to the left balancing a "skew" to the right. But, if the records fall into two general classes, one giving frequency polygons "skewed" to the left and the other "skewed" to the right, a bimodal curve results. Since the curve here found is unimodal, it follows that the "skewness" of the curves for individual stations, if it exists, is promiscuous in character. A study of the records of 33 stations with a total of 823 observations shows that the distribution is that of the "normal frequency curve," although there is a slight amount of "skewness," that is, the median does not fall exactly on the mean but is a fraction of a day earlier. Inasmuch as frost either does or does not occur on any particular

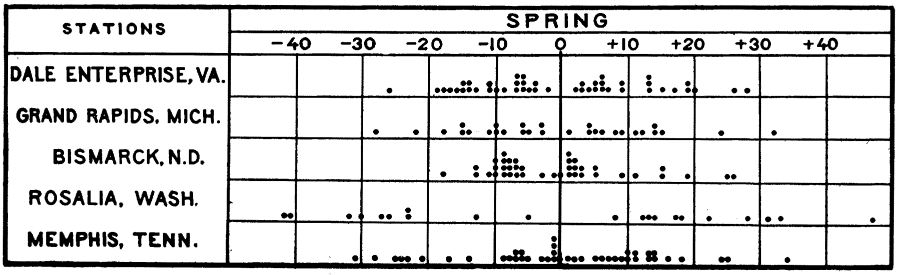

FIG. 1—Number of days before or after the average date on which the last killing frost in spring occurred in each year of record at selected stations.

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[5] See C. B. Davenport: Statistical Methods, 3rd edit., New York, 1914, pp. 11-13.

date, fractions of a date cannot be taken into account; this means that the normal frequency curve fits the distribution of the dates of last killing frost in spring as well as the slightly skewed curve for the combined data. Figure 2 shows the frequency polygon for the 823 observations and the normal frequency curve obtained from this polygon.

The properties of normal frequency curves have been carefully investigated.[6] From the results of this work it is possible to compute the percentage of occurrence of cases falling outside any given date or to compute the date beyond which a given percentage of cases falls. The characteristics of the normal distribution of frost dates (or any phenomenon in which the distribution follows that of the normal frequency curve) may be expressed by a single number, known as the "standard deviation."[7] When the standard deviation of the dates of last killing frost in spring is known for any station, the frost risk may be computed for any date by Table II.

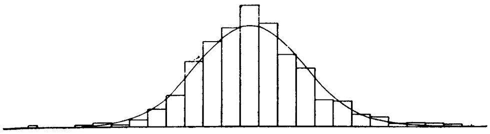

FIG. 2—Frequency polygon and most probable normal frequency curve of the date of last killing frost in spring for the combined records of 33 stations, comprising 823 observations.

TABLE II—RISK OF KILLING FROST IN SPRING

RISK OF OCCURRENCE	NUMBER OF DAYS AFTER THE AVERAGE DATE	EXAMPLE LACROSSE, WISCONSIN
50%	Average date	April 26
40%	0.25 × standard deviation	April 26 + (0.25 × 14.4) = April 30
30%	0.52 × standard deviation	April 26 + (0.52 × 14.4) = May 4
25%	0.67 × standard deviation	April 26 + (0.67 × 14.4) = May 6
20%	0.84 × standard deviation	April 26 + (0.84 × 14.4) = May 9
10%	1.28 × standard deviation	April 26 + (1.28 × 14.4) = May 15

The autumn date when the risk of killing frost rises to a given per cent may be determined by subtracting from the average date the numbers obtained by the use of the standard deviation of the date of first killing frost.

Figure 3 shows the standard deviations of the dates of last killing frost in spring for the United States. The isograms were drawn from the standard deviations determined for 569 stations fairly well distributed over the country; the lines are of necessity somewhat generalized. Figure 4 is a similar map of the standard deviations of first killing frost in autumn.

To compute the time available for plant growth in a given proportion of the years, the most satisfactory method is that based on the risk at each

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[6] K. Pearson: Mathematical Contributions to the Theory of Evolution (various papers), *Philos. Trans. Roy. Soc., London: Ser. A*, Vol. 185, 1894, *et seq.*

G. U. Yule: An Introduction to the Theory of Statistics. 2nd edit., Griffin & Co., London, 1912.

C. B. Davenport: Statistical Methods. 3rd. edit., Wiley, New York, 1914.

W. J. Spillman, H. R. Tolley, and W. G. Reed: The Average Interval Curve and Its Application to Meteorological Phenomena, *Monthly Weather Rev.*, Vol. 44, 1916, pp. 197-200.

[7] Mathematically this is the square root of the mean square of the departures of the frost dates in each year from the average of all years. (See C. B. Davenport: Statistical Methods, pp. 15-16.)

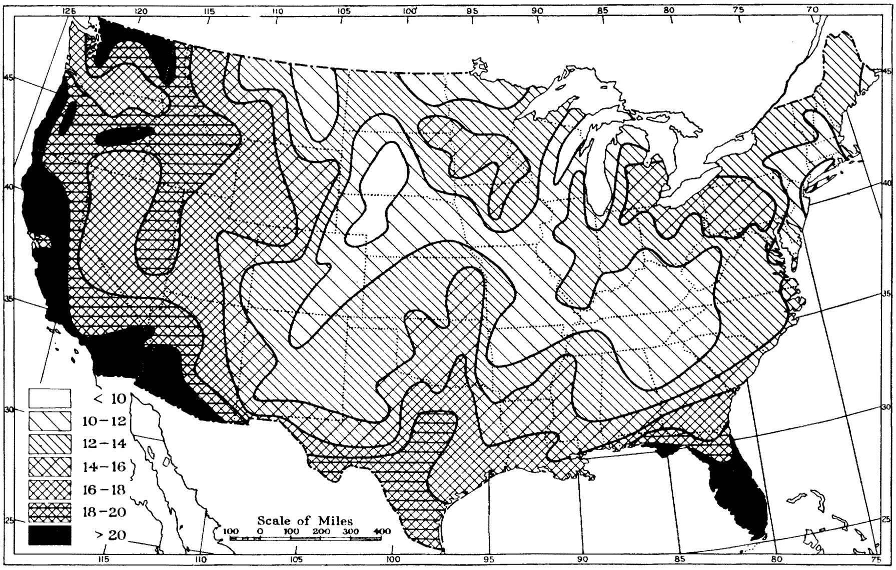

FIG. 3.

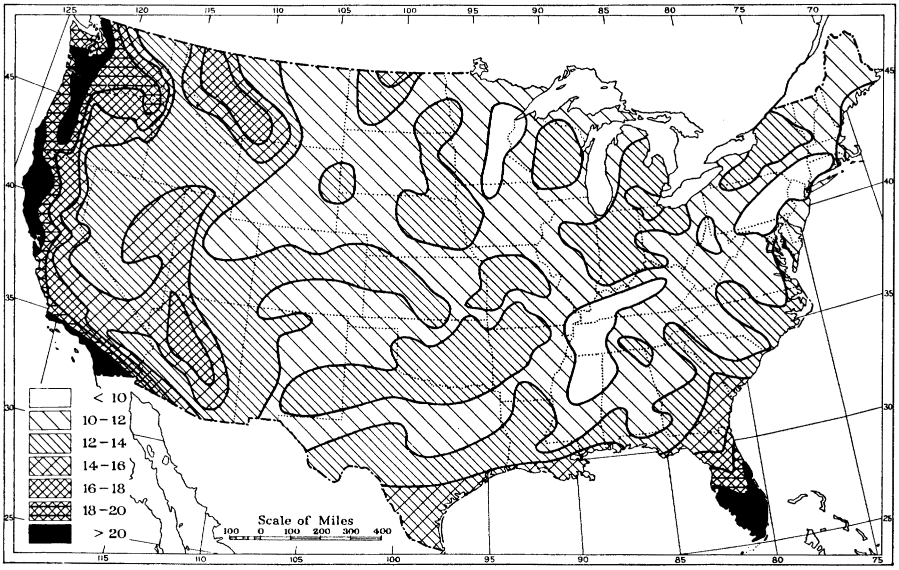

FIG. 4.

FIG. 3—Sketch map of the United States showing standard deviations of dates of last killing frost in spring, compiled from the records of 569 stations.

FIG. 4—Sketch map of the United States showing standard deviations of dates of first killing frost in autumn, compiled from the records of 569 stations.

end of the growing season. If plants are in a condition to be damaged at the average date of last killing frost, the risk to the crop from spring frost is 50 per cent. The risk to plants whose growth requires the whole time until the average date of first killing frost is 50 per cent for each crop which is carried through the summer. Therefore, the chance of a season without killing frost between the average date of last spring frost and the average date of first autumn frost is only 25 per cent.[8] Likewise, the length of a season with any given percentage of risk or safety may be computed. For example, the computed length of the season in which the chance of safety is about 80 per cent is the same as a season with a chance of safety in spring of 90 per cent (risk, 10 per cent) and a chance of safety in autumn of 90 per cent; the chance is that 90 per cent of the crops above ground on the date computed will be carried through the summer, of the crops carried to autumn 90 per cent will not be damaged by frost before the date computed for an autumn risk of 10 per cent.[9]

This method of determining the business risk the farmer has to meet is subject to limitations because of the shortness of the individual records. It is better, however, to determine the risk on the basis of the data for all the years of the record than on the basis of a smaller number of extreme cases. In general the two methods agree closely; of a total of 13,559 observations of last killing frost in spring 1,338 fell outside the computed date after which the risk is less than 10 per cent; if the agreement had been perfect the number would have been 1,356, making a lack of agreement of only 13 cases in 10,000; in the case of 13,600 observations of autumn frost the lack of agreement was only 21 in 10,000.

Statements of risk based upon the results of such a study as this should not be regarded as seasonal forecasts; they simply represent, as far as may be determined from the data now available, the risks the farmer must offset if his business is to be permanently successful. The risk of loss which may be profitably carried varies with the crop and the economic conditions. For those crops in which early production results in higher prices, such as garden vegetables, a considerable risk may be assumed and crops may be lost rather frequently with profit in the long run. In the case of other crops, such as corn, where early production is of little or no advantage, the risk which can be assumed will be much smaller.

Frost is but one of several unfavorable weather conditions involving business risks. The distribution of other phenomena seems to be more complicated, but further studies along this line will doubtless result in determining a method of computing the risk from their occurrence.

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[8] Mathematically this is the product of the two probabilities.
50% may be expressed as $\frac{50}{100}$, then

$$\frac{50}{100} \times \frac{50}{100} = \frac{2500}{10000} = \frac{25}{100} = 25\%$$

[9] $\frac{90}{100} \times \frac{90}{100} = \frac{8100}{10000} = \frac{81}{100} = 81\%$